Mathematical Modelling of Manufacturing Processes
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Lecture - 35
Micro/Nano Scale Manufacturing

Hello everybody, now I will start with the new module, mathematical modelling of manufacturing processes. So this is little bit in different aspect.

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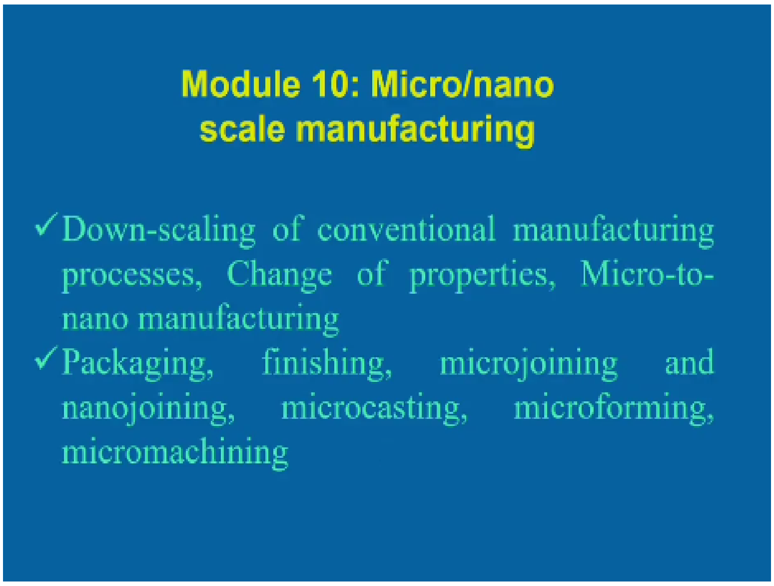

Not exactly the modelling of this thing, but rather more on that micro or nano scale manufacturing processes. We will try to get some overview of the different types of the micro scale or nano scale manufacturing processes, but this overview mainly focused on the joining or assembly of these 2 components. In that part I will try to focus here.

So of course in this micro or nano scale manufacturing most of the cases we start with the downscaling of the conventional processes and of course that sometimes it is necessary to interrogate the different length scale of the component. So therefore, the fabrication techniques for the different micro or nano scale processes and apart from that the different manufacturing processes relevant to the packaging, finishing processes, micro joining.

And nano micro, micro casting, micro forming and of course micromachining, all these aspect I will try to look into just to overview of this topics.

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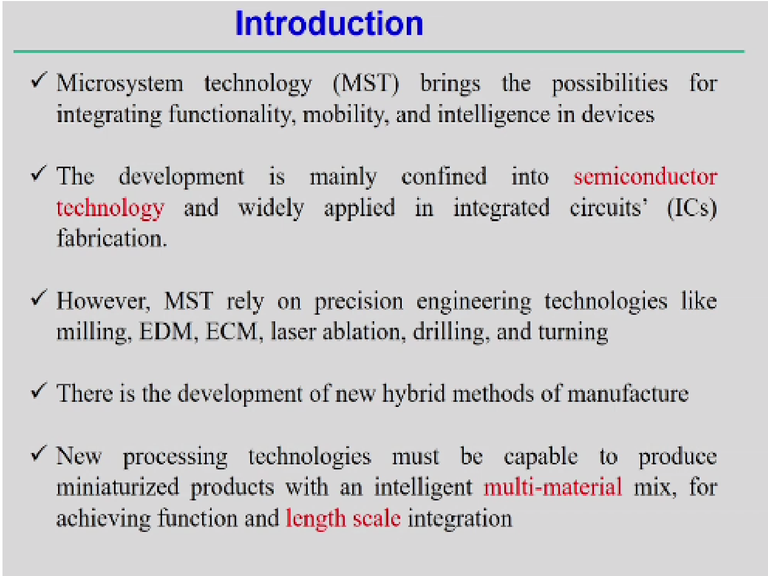

Now if you see that microsystem technology that brings the possibilities of integrating the functionality or different multi-material of course you try to bring some intelligence in the, to make some devices which is in micro scale or maybe nano scale devices so in that case. So actually most of the development in the micro scale normally confined to the semiconductor industries and last 2 decades there are so many developments happens in this area.

And of course apart from the semiconductor technology and that is mostly applied in the integrated circuit and these are the prime forecast in the last 2 decades of microsystem technologies, but of course apart from that microsystem technology can also be applicable or engineering technologies for example, by using the milling process so electro discharge machining, electrochemical machining, laser ablation drilling and tunnelling.

And the different scale we can possible to obtain different surface finish by using this type of different manufacturing technologies. So but nowadays with the development of the new materials and of course more complicated geometry and of course with the mini reduction of the size of the components. So therefore, new technologies has been developed or maybe hybrid technology has been developed that is related to the microsystem technology.

So we will try to look into that different manufacturing process, how we can bring from conventional processes to the micro scale processes. So therefore, in this cases new processing technology, therefore, must be capable to produce some miniature products and of course with the intelligent different multi-material mix and creating some interface such that it is possible to assemble the different component and of course for a particular achieving some particular function at the same time, at different length scale.

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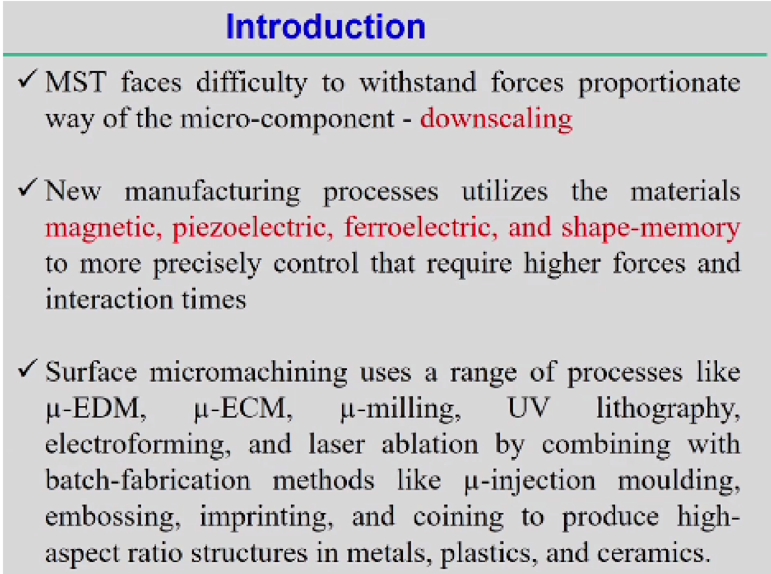

So if you see that most of MST that means microsystem technology actually faces the difficulty when you try to reduce from conventional manufacturing process to this micro scale manufacturing processes or maybe you can downscaling the processes, maybe sometime it is not possible to proportionate way, the very the force components and of course this components of the force depend on the size of the components.

So there maybe some reduction in the force component maybe necessary when you are downscaling the conventional processes. So therefore, new manufacturing processes try to utilise some different types of the mechanism of the particular material, developed material. For example, magnetic, so rather controlling of the force using some magnetic material, piezoelectric material, of course ferroelectric and shape-memory.

Such that it is possible to control the force very accurately and at the same time some controlling of all this different kind of forces and then with the particular reaction time, so that is also important in the microsystem technologies. So using all these different new develop materials, the development of the new technology is going on in the specific application in the or to produce some kind of micro devices or nano devices.

Of course if you look into that different surface micromachining processes there is wide varieties of processes available, for example, micro electro discharge machining, micro electrochemical machining, micro milling ultraviolet lithography, electroforming and the laser ablation by combining with the batch fabrication methods like micro injection moulding, embossing imprinting and coining.

To produce high aspect ratio structures in metals, plastics and ceramics, so all this we can find out the application in any kind of the microsystem technology using all this kind of materials.

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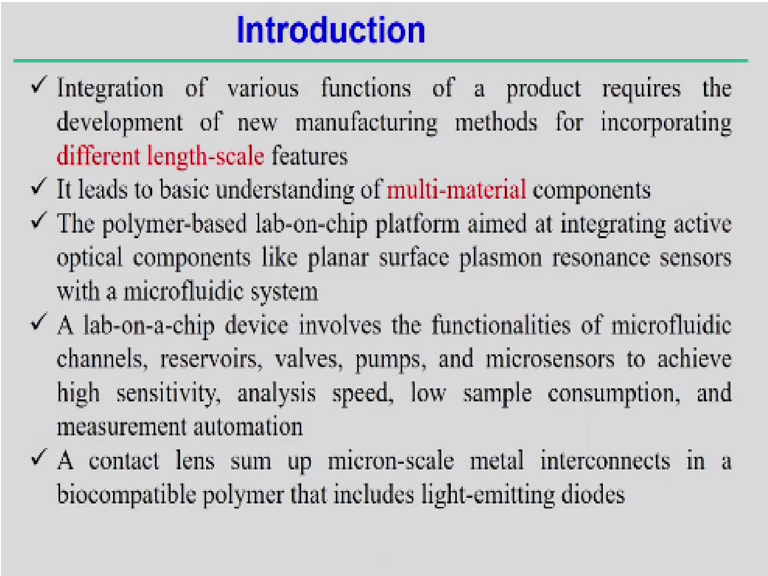

But of course integration of the various functions of the products is the main part of the micro system technology and that is the job of a development or that is the drive for the development of the new manufacturing methods such that it will be possible to incorporate different length scale features. So that is the more challenging task also in microsystem technologies processes.

And of course it is also necessary the basic understanding of the different multi material companies, their responses and of course that is necessary what we can integrate the different component to produce one device. So therefore, for example, the polymer based lab-on-a-chip platform they actually integrating the active optical components like planar surface, plasmon resonance sensor with the microfluidic system.

So when you try to look into this integration of these resonance sensors with a microfluidic system then it become challenging in a micro devices and of course here necessary to actually handle the different types of the material and what way we can interact with respect to different material that is also a typical difficulties in case of microsystem technology. Even if we look into the lab-on-a-chip device involves the functionalities of the microfluidic channels involved, the reservoirs, valves, pumps, all are integrated microprocessor.

All are integrated to very small component even to achieve high sensitivity and having the individual load very analysis speed, very low sample consumption and measurement automation, all are actually involved in case of lab-on-a-chip device. So therefore, this is the model device if you try to look into that then we need to know the mechanism of the different components we have utilised here when you are interacting with this, all these different components and their response in this component.

So that is also important for analyse and in general for another example you can look into the contact lens some of microscale metal interconnects in a biocompatible polymer that includes light emitting diodes also, that way contact lens and that this understanding of this mechanism opens up the nude idea of the development of the new technology as well. So in that sense we need to understand that different mechanism, which mechanism is responsible apart from this they are manufacturing of all these components.

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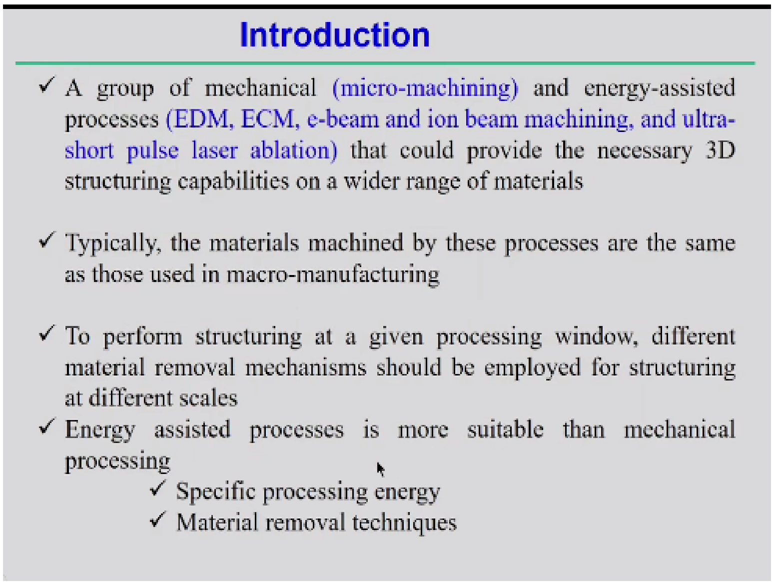

So even if you look into that different group of mechanical and energy assisted that normally used in a micro system technology for example, micro-machining, micro milling, diamond machining that can also be used. So therefore, even apart from that is the mechanical finishing process, machining process, apart from that energy assisted process. So for example, electro discharge, electrochemical, electron beam, iron beam machining and ultra short pulse laser ablation.

All these cases it is possible to control, it is a very minute material removal, or may be affected zone very small, all this cases, when you try to develop from conventional to the micro scale component and of course this what extent we can use depends on the which we have to look into that length scale of this component we are supposed to use. So therefore, all this mechanical and energy assisted processes we assemble together.

It is possible that could provide the three-dimensional necessary structure taking the advantage of all the different types of the manufacturing processes and of course all this processes can also be applicable for wide range of material. For example, one process maybe applicable for the metallic material at the same time that it may not be applicable for the non-metallic material.

So therefore, wide range of materials coverage are there if you group a mechanical or if you know that each are individual manufacturing processes and their response in the when you try to downscaling of this processes. So therefore, typically the materials machines by this process are the same as those used in the macro manufacturing, but of course same method, same principle we use it.

But of course in the micro manufacturing cases all that we normally downscales the conventional processes. For example, to perform structuring at the given processing window, different material removal mechanism need to understand and which is responsible for structuring at different scales. So therefore, if you look into the mechanical assistant and energy assistant processes.

Basically, finishing process we can say or machining process we can say. So in this cases the energy assisted process is more suitable than mechanical processes or more accurately we can utilise these things and of course this nonconventional for example, electrochemical machining is more applicable to even for the wide range of the materials as compared to the conventional processes.

So therefore, some development happens in that particular area. So if you look at that 2 specific parameters we can decide that this microsystem technology, one is the specific processing energy, water using and second is the material removal techniques and what type of material removal techniques we can look into just different and of course and the different processes or different length scale the amount of the specific energy requirement will be different for all this cases.

So therefore, then if we know this parameters range, it is possible to interrogate the manufacturing of the component having 2 different lengths scale.

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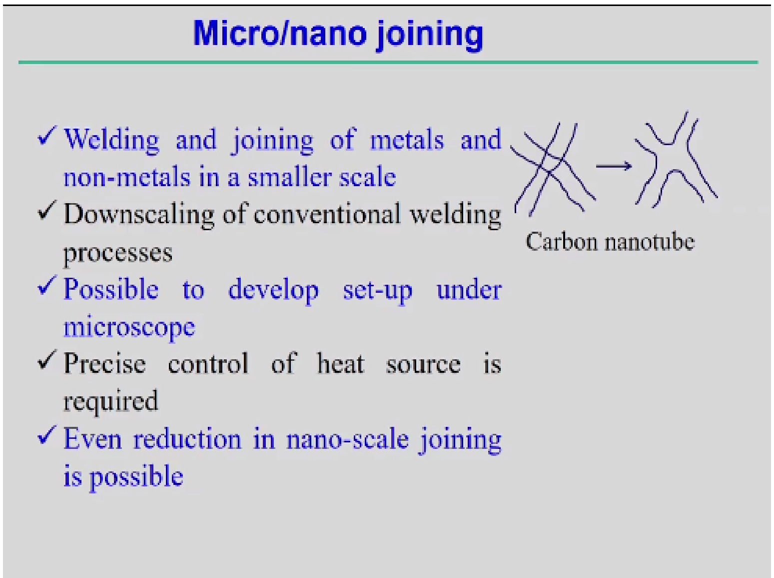

Now not exactly going back to but rather I am trying to focus on this one of the micro manufacturing technology that we just that is called the micro or nano joining processes or sometimes we call it is micro nanowelding processes. So we just try to look into the what are the different developments happens in case of the micro or nano joining processes.

So it is of course, it is one of the basic manufacturing processes in manufacturing processes apart from machining, casting and forming and finishing all their development also happens all this conventional manufacturing process at the microscale. Now if we look into that micro scale or nano scale joining processes. Of course in this cases it is required in microsystem technology the handling of the both metallic material and non metallic materials.

And of course the handling should be in a relatively smaller scale. So it is a simply downscaling of the conventional welding processes we can develop, the micro or nano joining technologies of course more precisely it can goes to the nanowelding technology or nano joining technologies, but in general, the difference from the conventional process is that what we can control the heat source.

So intensity of the heat and the amount of the heat flux we apply in to the substrate for any kind of the processing of joining processes. So controlling of this is the main features for the development of the micro nano scale joining process.

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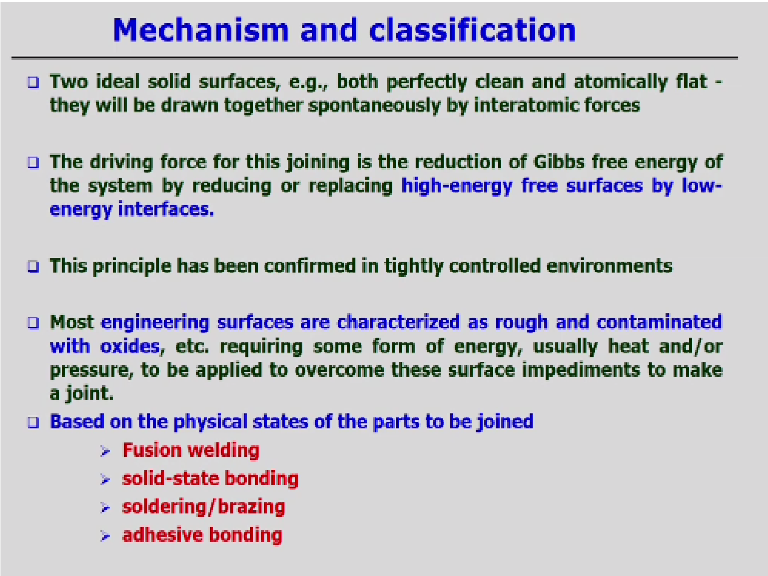

People look into the mechanism of the, basic mechanism of the metal joining or welding processes. It is like that if 2 surfaces are perfectly flat and they are atomically flat of course and perfectly clean. Then if you bring together this 2 surfaces they actually spontaneously joining by interatomic forces, but we have to prepare this kind of surface. So normally presence of the surface in particular component that actually hold some large amount of the Gibbs free energy.

So if it is possible to reduce the Gibbs free energy by reviewing the high energy surfaces to low energy interfaces, if we create that kind of the situation than 2 surfaces can be joined more easily, but in general if you see the most of the engineering services contaminated in the form of the oxides layer or some other or either are contaminated in the or there is rough surfaces if that rough surface maybe if you look into the microscale.

So therefore, some sort of energy is required to remove this oxide layer and of course in the most of the case we put this heat can we directly apply the heat or some frictional heat or with the application of the pressure such that to remove this impurities exist over the surface and they bring the contact or may bring these 2 surfaces in contact that helps to join between these 2 components.

So therefore, in principle some amount of the energy is required if you want to join these 2 surfaces and this surface is characteristics 2 things, one is the minimization of the Gibbs free energy of the surface and second one is it should be atomically try to bring in that situation, this will be atomically flat. So in that cases it can easily be joined, these 2 components.

So based on the physical states of the parts to be joined actually in the all these 4 categories, fusion, welding, solid state welding, soldering, brazing and adhesive bonding, all these cases there is a development on the microwelding is done.

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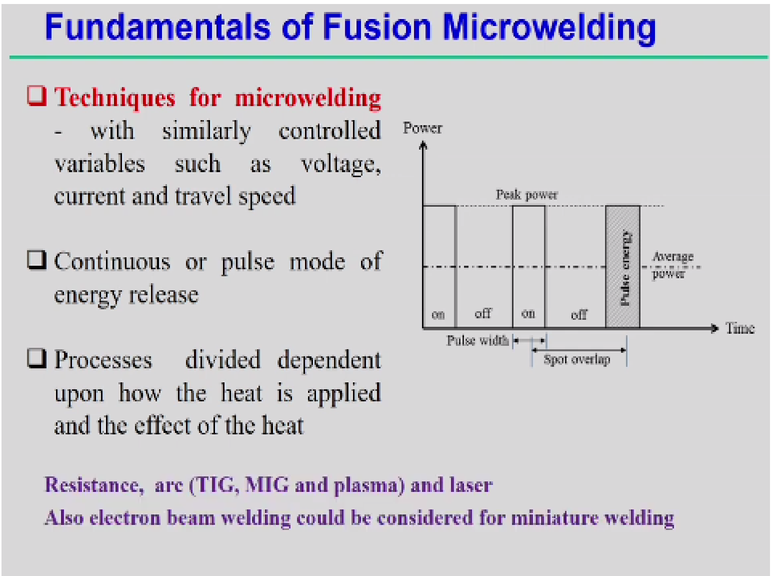

Now in general if you look in to the microwelding, suppose most convenient way for the development of the microwelding processes from conventional to that microwelding simply downscaling apart from the decreasing the intensity that it can be done from continuous mode to pulse mode because it in pulse mode it is possible to control the energy supplied to the substrate material.

And of course that is why pulse laser is most suitable and most of the development of the microwelding system has been done based on the using the pulse welding process. So apart from using the low power intensity laser. So therefore, techniques for microwelding it is similarly, control variables of the voltage current and travel speed in case of microwelding processes, it can be continuous or pulse mode, even continuous mode.

Then definitely continuous mode, we do not have much option because in this case only the reduction of the power or intensity is possible, but when you try to look into pulse mode, there is a looking into the pulse mode relation strategy we can vary the intensity of the power. So therefore, or maybe we can reduce the average laser power which is average laser for say to some extent, equivalent to the continuous mode of laser.

And of course not only laser also this reduction of the pulse mode is also available even for arc welding processes also. So therefore, in general that microwelding system is can be developed to looking into that influence of the or either continuous mode or more effectively from the pulse mode of operation. So if you look that in microwelding system this is mainly for resistance, arc welding, arc welding technique TIG, MIG and plasma and laser.

The development happens in the microwelding system, apart from that also electron beam welding could be considered for the miniature welding process. So we will try to discuss this at basics things of development of the different micro scaling welding processes.

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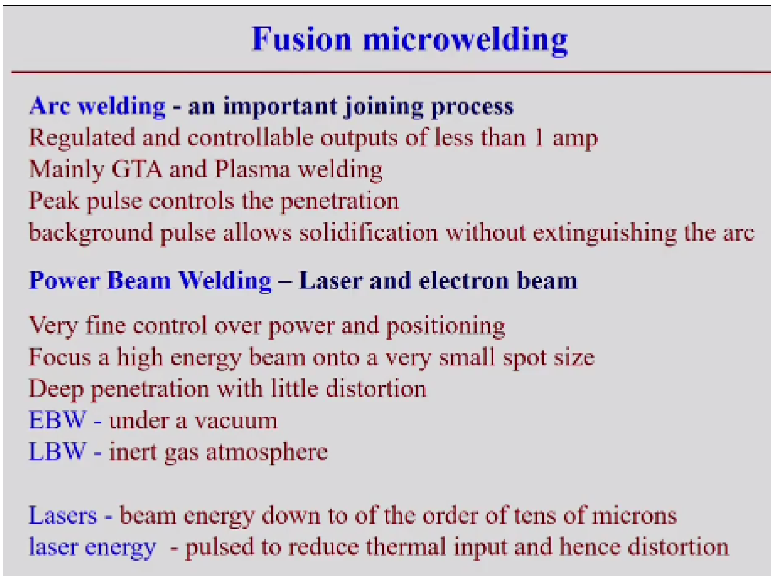

Now fusion microwelding of course fusion microwelding the processing can be done by heating the material above the melting point temperature then we allow the solidification for a particular material, metallic material and then after solidification we can get the structure. Of course when you look handling the microwelding or telling the microwelding system the material volume may be handling is very small in this cases as compared to the conventional process.

And of course thickness may be restricted to less than 500 micrometre of a particular component we can say it is a kind of microwelding process, but microwelding development has been done even in arc welding processes, but presence of the regulated uncontrolled output of less than 1 amp and that is possible even for GTA TIG welding processes, it is possible to use in the pulse mode even for plasma arc welding process, it is possible to use in the pulse mode.

So they can be used in the microwelding application. So mainly the development happens in GTA and plasma microwelding processes and peak pulse controls the penetration, so intensity control the peak pulse, that means what is the peak power controls the penetration and of course that ground or base current sometimes allows the solidification without extinguish the arc. So that is the main features in arc welding processes.

If you look into the power beam welding processes both the laser and electron beam welding process is mostly develop in the microwelding application. In this case very fine control over power and position is possible and that is why are use mostly the very precious and microwelding application the laser and electron beam is the most suitable source and as compared to the arc welding processes.

Of course and it is focus because laser can be or electron can be focus into very small area or may be limited heat affected zone can we produced using the laser. So that can be advantages to develop the microwelding processes and of course deep penetration can also process because high intensity laser can be used and with that little distortion can be controlled even if you use the laser also.

But electron beam welding process all the process has been performed under the vacuum and of course laser beam welding normally you can use the kind of inert gas atmosphere and of course this electron beam and laser beam welding process having advantages or development of the microwelding system but of course in terms of the cost, this electron beam or laser beam microwelding process is little bit costly as compared to the arc welding process.

But till the development also have done in arc welding process, but if you want to look into very small is very precision welding process even it is accuracy level very small even length scale is very small, so in that case probably the laser or electron beam welding is the more suitable processes for the development of the microwelding system. So laser beam energy down to the order of the 10 of a micron that can else be possible.

And even laser energy that pulse basically, pulsation reduce the thermal input as well as reduce the distortion that is the disadvantage of using the pulse laser mode in microwelding processes. So apart from that some solid state bonding also develop in the that is in the category of the microwelding or micro joining processes. Of course in this solid state bonding process, no melting happens.

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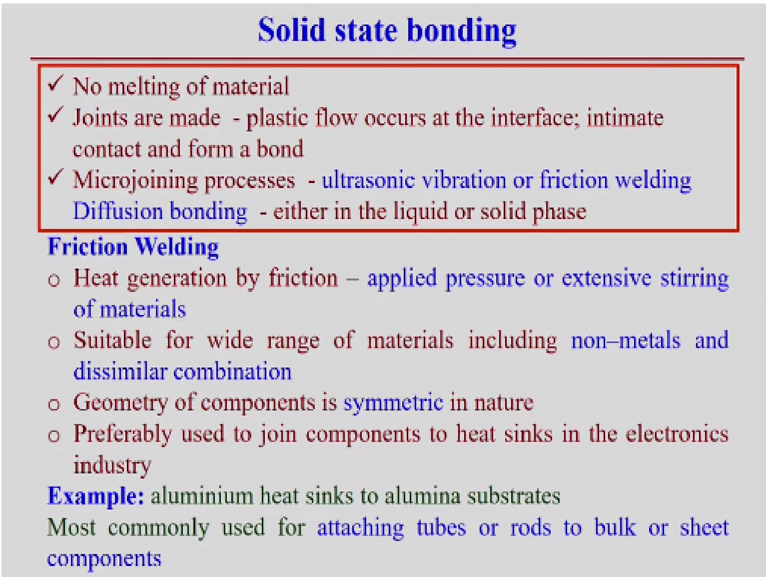

Joints are made and the plastic deformation at the interface and intimate contact and finally, from a bond, sometimes it clear some kind of the morphology such that they after plasticization they create some interlock in the surfaces from one surface to the another surface and in this case microjoining processes normally in the solid state ultrasonic vibration or friction welding and diffusion bonding, these are the main development.

And either in the liquid or the solid phase, these are the most suitable processes in solid state bonding processor. Friction welding in this cases the friction heat generation by the friction, heat actually generate because of the friction and with the application of the pressure and extensive stirring of the materials and even nowadays the development of the friction stir welding also happen at the microscale.

And in this case solid state bonding process is mostly suitable wide range of materials and of course apart from that non metals cannot be used here and dissimilar combination is more advantageous with the application of the solid state bonding processes. Because dissimilar welding process melting of the, when you try to fusion welding will be applied for the dissimilar joining process in most of the cases it clears some kind of the intermetallics.

And which maybe little intermetallic due to the joint strength and life of the welded joint. So in that sense solid state bonding is for dissimilar material combination is more suitable. So that is why some development happens in the solid state bonding process, but one limitation in friction welding is geometrics should be symmetric in nature and preferably used for joining components to heat sink in case of electronics industry.

We can get the application, the joining of the heat sinks in the electronics industry one of the more practical application of the solution bonding process or friction welding processes, example aluminium heat sinks to aluminium substitute and try to join the fiction welding is one of the suitable method here. So most commonly used for attaching tubes or rods to a bulk sheet, we normally follow kind of the friction welding process even it is in the micro scale.

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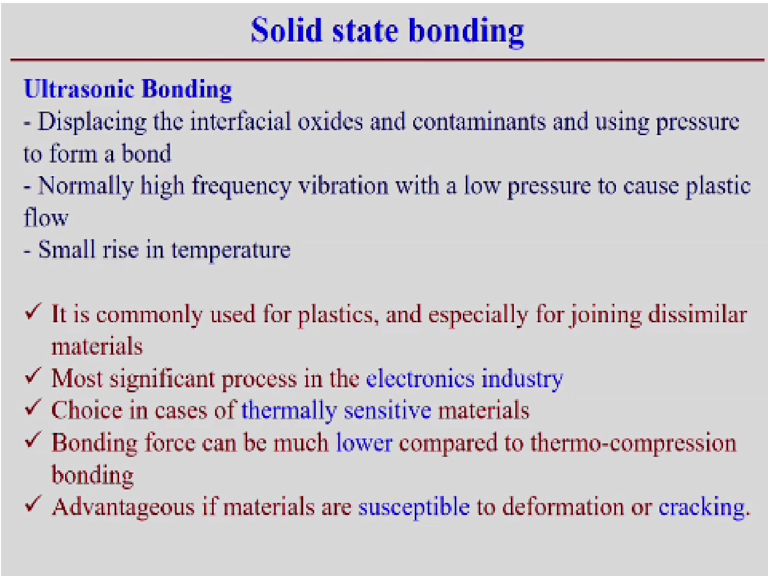

Ultrasonic bonding is another type of the solid state bonding process, in this case the ultrasonic vibration we create here to displacement of the intern metallic oxides or contaminated layer removes by using the pressure to form a bond. So normally high frequency vibration along with the low pressure is responsible to cause the plastic deformation and this can be applied in every localised space.

So in localised area, sometimes even we use the ultrasonic source for the microstructure modification also. So definitely since it is confined, it is a very small zone and small rise in the temperature in this solid state bonding process. So it is mostly used in case of plastics and especially for joining of the dissimilar materials, more significant process in electronics industry within use this ultrasonic bonding process.

Choice in case of thermally sensitive material, so thermally sensitive materials in that cases, the ultrasonic is the more suitable process, ultrasonic bonding and in this cases bonding force can be much lower compared to the thermo compression bonding other cases and it is advantageous if the materials susceptible to deformation or try to form the crack, so that type of material is more suitable with the application of the ultrasonic bonding process.

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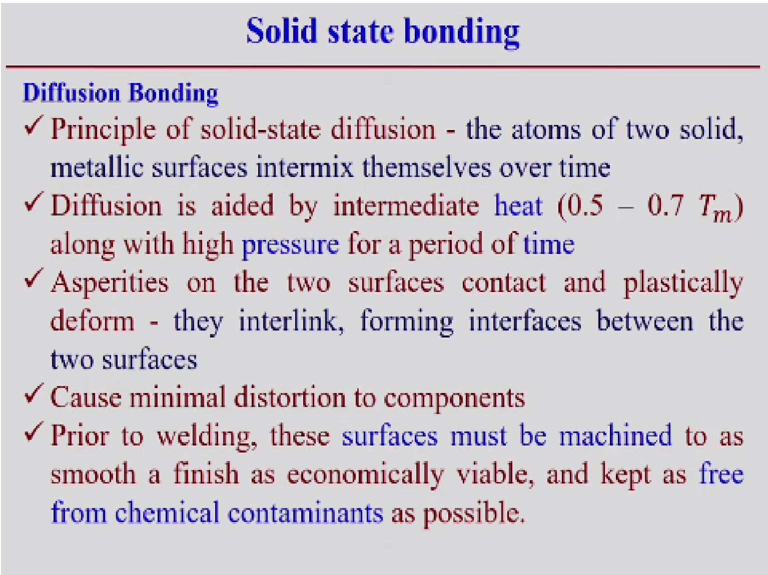

Solid-state bonding if you see, the solid state bonding one is the diffusion bonding, the principle of the solid state diffusion is the atoms of the 2 solid phase come in metallic, interfaces come in interact with this with each each and that we get to hold for a sufficient time such that allow to diffusion occurs between the 2 layers, but of course in this cases the diffusion is aided by the diffusion can be accelerated by application of the small amount of the heat.

So around point 50% to 70% of the melting point temperature along with the pressure for a period of time. So now 2 things are important here in the solid state bonding process, the aspirate is we are in contact that is also physically deformed with respect to each other, so the asperities is one important aspect and apart from that the removal of the oxides layer what way we can remove the oxides layer, such that intimate contact between the 2 surfaces may happen in this cases.

So when asperities of the 2 surfaces contact and physically interlock with respect to due to the plastic deformation, so in this cases it is forming the interfaces between the 2 surface by plastic deformation and this is very localised area it is possible to do the diffusion and this diffusion is mostly not associated with the change in temperature, so therefore, minimal distortion to the components happens.

So prior to welding the surface preparation is one of the important aspects to get the successful diffusion welding of the components. So as minimum as possible to remove the contaminated layer from the surfaces, then diffusion bonding becomes more successful as smooth surface finish economically viable and kept as free from chemical contamination as possible that is the more important aspect in case of the diffusion bonding process.

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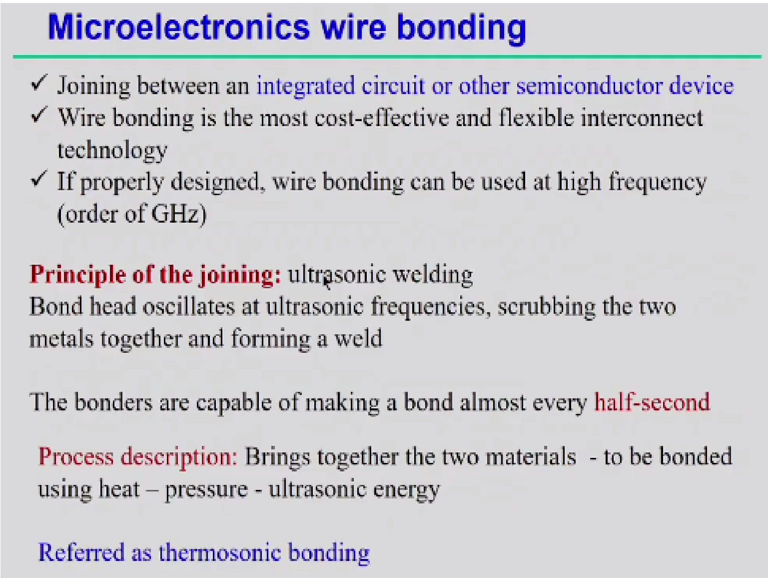

Now one of the application of this diffusion bonding, solid state bonding of the microelectronics wire bonding, we can get the application of the microelectronics wire bonding, so basically, joining between an integrated circuit to a semiconductor device. So when bonding is the most cost effective and most flexible interconnect technology normally happens and it properly designed bonding, instead of high speed bonding can be done at very high frequency the order of giga hertz.

But principle of the joining best components bonding is basically, ultrasonic welding process, sometimes this ultrasonic welding process added by the some kind of the heat. So that is called the thermosetting bonding process. So in this case bond head oscillates at the ultrasonic frequencies and scrubbing the 2 metals together and form a final forming a weld. So therefore, the bonders are capable of making a bond almost every half second.

That means this is the very fast process and brings process description vacancy, brings the 2 materials together to be bonded using pressure as well as the ultrasonic energy if we apply both together then that is called the sorry heat pressure energy all 3 we can apply together then it is called, referred to as the thermosonic bonding process.

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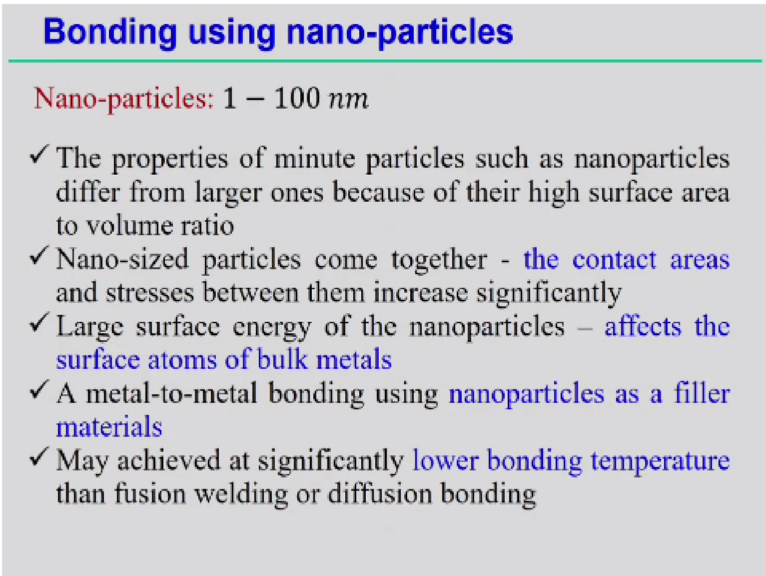

Even bonding using nanoparticles we know that the nanoparticles normally the size of the nanoparticle is in between 1 to 100 nanometre, so in this cases, the properties of this very this size less than 100 nanometre particles is completely different from the conventional particles which is size is bigger and because the main aspect is the volume by area ratio is very much high in case of the nanoparticles.

So the properties actually depends on this volume by area ratio, which has a surface area to the volume ratio. So in this case so that is the huge differences between the size of the particle, if you reduce the size of the particles, there is difference in the surface area to volume. So therefore, nano size particles when come together the contact areas or stress between this together and then increasing significantly.

So when 2 interfaces is filled with the nanoparticles, so when we apply the pressure so basically, surface area increases significantly, so large surface area of the nanoparticles affects the surface atom of the bulk metals. So therefore, a metal to metal bonding is more strong by with the using of the nanoparticles and they act simply as the filler metals. So therefore, may achieved at significantly lower.

So this kind of joining may also achieve significantly lower bonding temperature, then fusion welding and diffusion bonding process.

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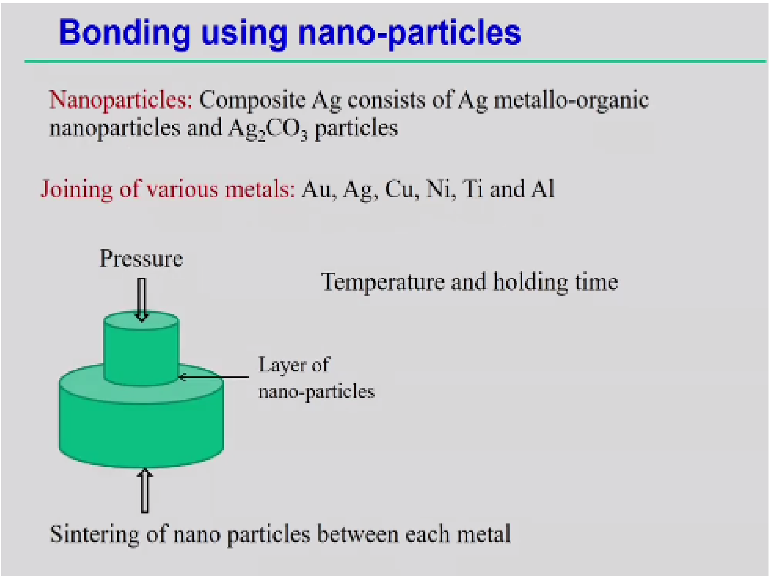

If you see bonding using nanoparticles that composite silver, consists of the silver metal organic nanoparticles and Ag2CO3 particles, if you look into this are the typical nanoparticles we use and if you look into that between these 2 components from the figure the layer of the nanoparticles is basically, filled between these 2 components and we simply apply the pressure.

So therefore, joining of the various metals can be done for example, silver, gold, copper, nickel, titanium, aluminium, all can be joined and the more important part is the temperature and the holding time zone important parameter to get the bonding strength. So here for sintering of the nanoparticles between the each metal with application of the temperature and of course, if you hold in for a sufficient time.

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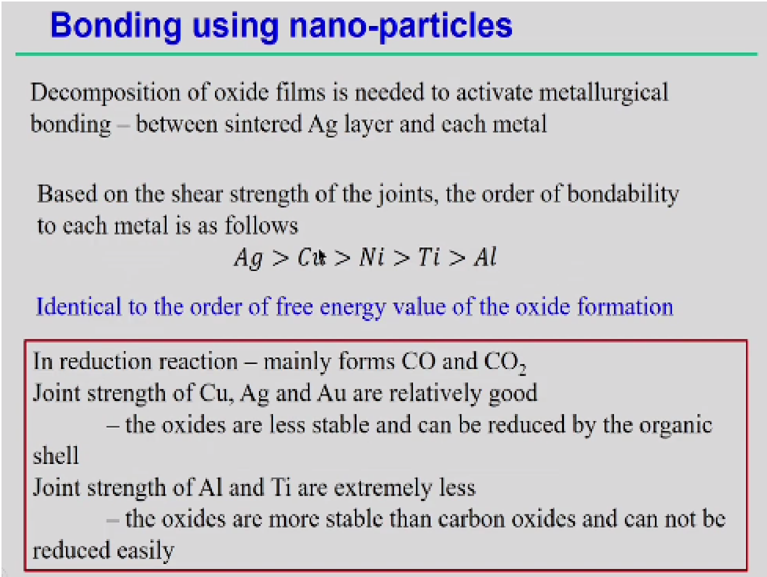

But if you look into that effectiveness of these joint it depends on what type of materials we are using, so because the decomposition oxide films is need, so initially the surface maybe some oxide surface are there, so we need to remove to activate the metallurgical bonding. So using the activate the nanoparticles between the 2 surfaces, so the surfaces the oxides layer has to be removed first.

Such that then directly the nanoparticles come in contact with the actual metal. So then it will be more easier to bond between these 2 components. Now based on the shear strength of the joints the bondability of the each metal can also be ranked in this way for example, the maximum bondability is for silver, then copper, then nickel, then titanium, and alloy and actually identical to the order of the free energy value of the oxide formation.

So if you see the free energy value of the oxide formations, oxide layer formation are different for these things and if you rank it, it is the similar rank here we have already mentioned in this cases. So in this case what happens, the reduction reaction normally happened that produce normally CO or CO2 carbon monoxide and carbon dioxide. So in this case the joint strength for copper, silver and gold are relatively good.

If you see they are in the copper, silver and gold, you can say this are relatively good because the oxides are in this cases less stable and we can remove this oxide layer by reduced reaction. So we can easily from the CO, CO2 just to remove this oxide. So in that cases bondings then becomes more strong in this cases, but of course in case of aluminium and titanium, it is very difficult to remove the oxides layer as compared to the copper and silver and gold.

So therefore, the oxides are more stable in case of aluminium, titanium, so in that cases when you try to use the nanoparticles for bonding these 2 nickel or titanium or aluminium surfaces. So in this cases we cannot produce that much of strength between these 2 components like silver and gold and copper.

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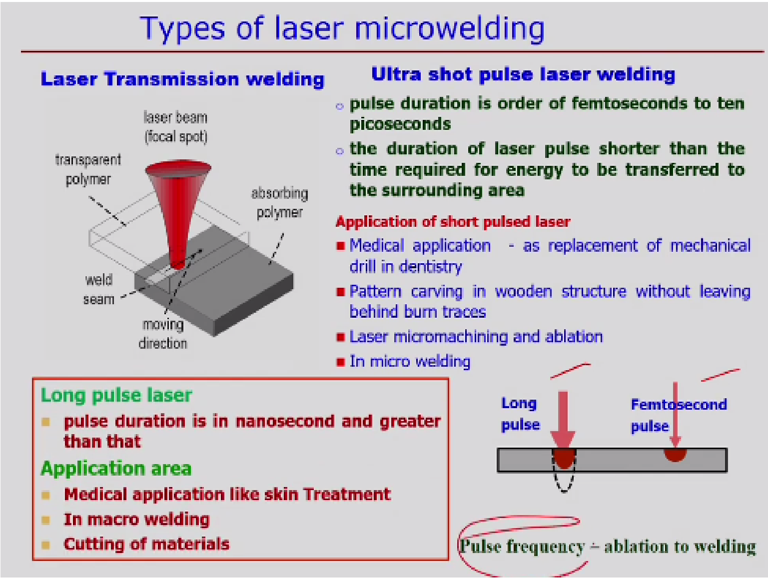

Now we can look into the different types of the laser and which is used the microwelding or there is a development of the laser microwelding processes. One is the laser transmission welding. Actually this laser transmission welding, it is possible to join 2 transparent material, but of course when we use the 2 transparent material. So laser passes through the transparent material, but absorptions would have been happened at the interface.

So in this case if both materials having the similar transmission to the particular laser or wavelength of this laser we are using in this case, some absorbing mediums should be there at the interface such that it can absorb the laser energy, energy will be released at the interface and then at the interface the bonding can happen between these 2 components. So this is the typical features of the laser transmission welding.

Of course one metal is transparent and another metal is not transparent. So definitely we not necessary to use some kind of the observing media at the interface. So at the interface, laser release the amount of the energy, laser energy such that at the interface the bonding between the 2 components may happen. So laser transmission welding is one of the application we can getting, so many application in the medical field even in microwelding application.

So apart from that ultrasound pulse laser is one suitable source for the development of the different microwelding, even actually the ultra shot pulse laser process, ultra shot pulse laser is normally used for the material ablation, is more established in this process, but using the ultra shot pulse laser that is established only for non metallic material, but it is not well established in case of the metallic material joining the 2 components.

But still there is a scope to development of this ultra shot pulse laser welding process specifically application in the micro scale component. So pulse deviation in this cases, ultra shot pulse duration is of the order of femtosecond to 10 picosecond which is shot pulse as compared to the conventional laser pulse because conventional laser pulse either micromilli second even for nanosecond pulse can also be produced.

But when it goes to the order of the femtosecond to 10 picosecond then we can say this is the ultra shot pulse. Though mechanism of the ultra shot pulse laser is completely different as compared to the other conventional laser. In this case the duration of the laser pulse is shorter than the time required for the energy to transfer to the surrounding area. So that compatible with each other.

So therefore, absorption or material removal from the surface is completely different as compared to the other conventional processes. Now application to short pulse laser, the medical application for example, as replacement of mechanical drill in dentistry. In the dentistry we can get this application of this ultra shot pulse laser pattern curving in the wooden structure without leaving behind burn traces.

So that we curve exactly we can producing the minimum amount of the heat affected zone almost no heat effected zone, the material ablation can also be possible using the ultra shot pulse laser, that is advantage of using this laser and of course laser micromachining and application is applicable using the ultra shot pulse laser and some cases we can most of the non metallic or metallic to non metallic cases we can find out the microwelding application using the ultra shot pulse laser.

If you see this figure, the long pulse and femtosecond pulse, if you see the long pulse having some molten zone or vaporised zone depending upon the intensity of the laser, but in this case it clears little bit more the heat affected zone, but if you look into the femtosecond, that exactly that very small area and very controlled way we just remove the material or the same time it is possible to join the 2 components.

But the pulse frequency is one parameter that actually decides whether ablation mechanism is active or it is possible to change from ablation to the welding mechanism. So if you look into long pulse laser, pulse duration is nanosecond or even greater than that, so that pulse duration laser we normally call as the long pulse laser. Application area, medical application like skin treatment also you can use macro welding processes, cutting of the materials can also be used in the long pulse laser.

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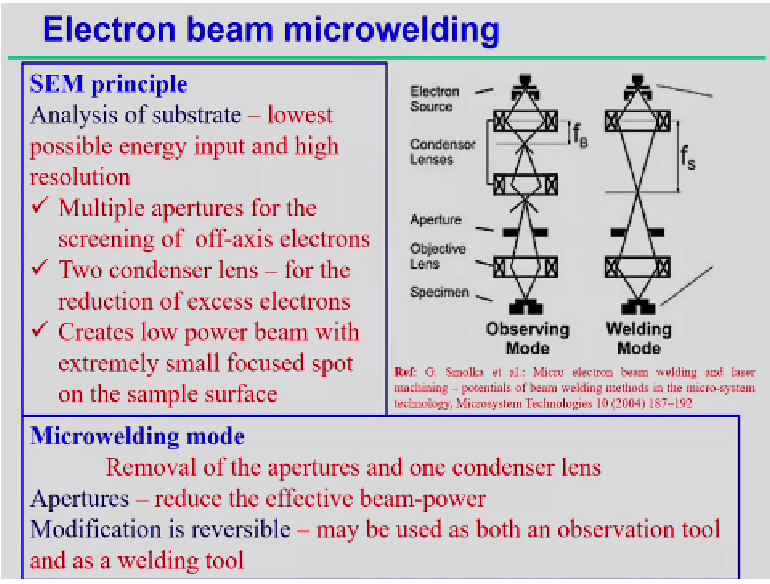

Now there is some development event for the electron beam microwelding processes. So in electron beam microwelding processes, it follow the scanning electron microscope principle So it is possible to develop the microwelding application for electron beam welding process, just using the principle of the scanning electron microscope or it is possible to convert scanning electron microscope to the electron beam microwelding process.

So what we can see that in SEM principal you can see the analysis of the substrate, lowest possible energy input and the high resolution that is the principle of the scanning electron microscope, but of course in this cases, there must be some electron source and we control in such a way such that the high resolution picture it is possible to capture in the observing mode.

So for this purpose some condenser lens is used, aperture is used, objective lens and the specimen, this is the typical structure of the scanning electron microscope, here you see, multiple apertures for screening of the off-axis electrons for that purpose we can use the multiple apertures it is possible to use, 2 condenser lens for the reduction of the excess electrons that can be used, that is the purpose of the using the condenser lens.

And finally, creates low power beam with extremely small focused spot on the sample. So that is the principle of the scanning electron microscope, but this can be converted to the electron beam microwelding process. In this case if you try to use this microwelding mode of this scanning electron microscope what we can do? We can do the removal of the apertures, one, removal of the apertures and one condenser lens if you remove it then the structure can be modified like this.

So it is focus length is increased here and condenser lens we just remove here and aperture we can remove here and then we simply getting the welding mode. So in this case apertures actually reduce the effective beam power and in this case modification reversible may be used as a both observing tool and as well as the welding. So hear 5 or 6 watt power can be generated from this scanning electron microscope when you convert just removing some condenser lens and aperture.

Then, it is possible to use as a welding mode such that 5 to 6 watt power can be produced. So this micro electron beam in this way it is possible to develop the micro electron beam welding process.

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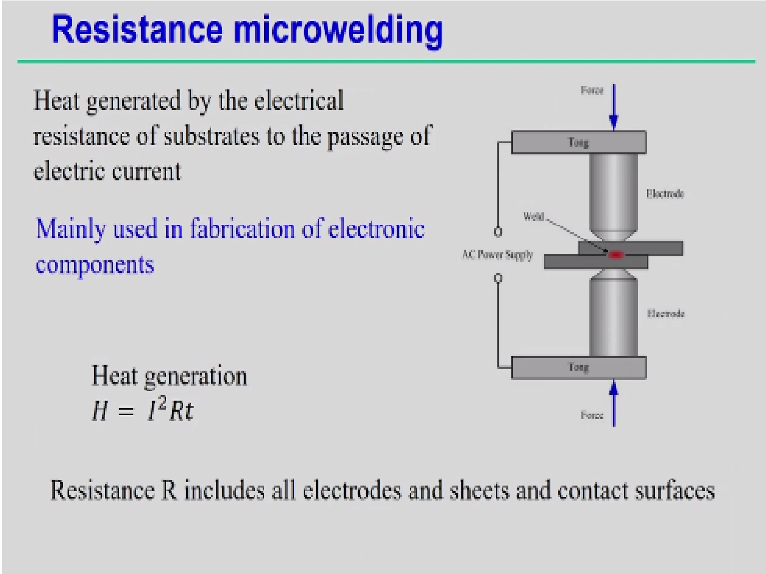

Even there is a development of the resistant microwelding process, so use the same principle in the resistance spot welding process, hear the heat generated mainly the electrical resistance and when it passes through the high current through the electrode and that with this very small duration and that creates the heat, the surfaces, the contact surfaces because of the contact resistance at the services creates that melt the surfaces.

But of course the contact surface between the electrode and the workpiece is the heat generation will be minimum because at this contact the resistance is very small and at the same time if you use the high conductive material as the electrode. So even heat is generated at the interface between the electrode and workpiece. So it will be immediately carried away by the high conductive electron material.

So in conventional processes, this high conductive electron material normally use water cooled electrode such that rate of the heat transfer can be effective when there is a heat generation between the electron and the work piece. We can easily estimate what is the amount of the heat generation by this using this equation H = I square Rt. So I is the applied current, R is the resistant, t is the time over which the current is applied.

So therefore, resistance R includes all the electrodes, sheets and contact surfaces, but the melting happen to the resistance between these 2 contact surfaces or some construction radiation must be there because this is the flow of the current path and that depending on the what is the contact area at this surfaces. So accordingly the heat generates at this contact surface.

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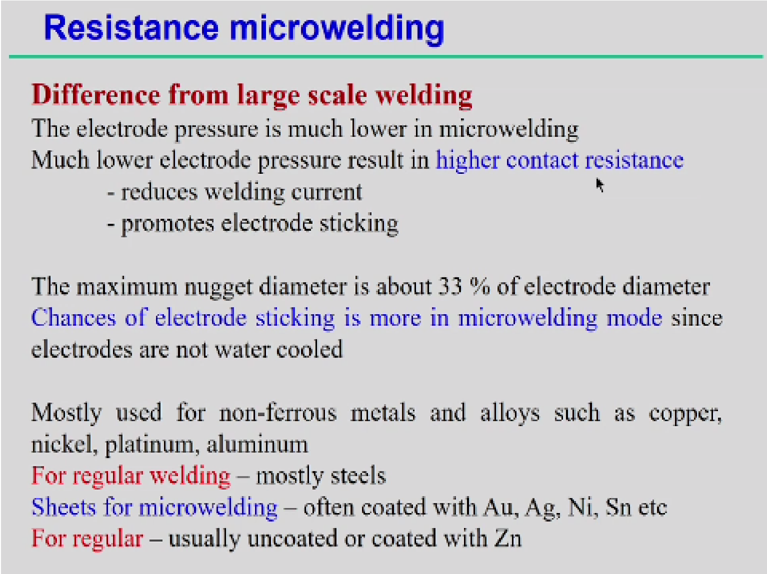

Now resistance microwelding is actually simply downscaling of the conventional processes, but there is some difference between the large-scale or conventional scale welding process with the micro resistance welding process. So in this cases the large scale process, the electrode pressure is much lower in microwelding process, but if it is conventional process, the electrode force is much higher.

So much lower electrode pressure results in the higher contact resistance. So if force is very small then it is lacks of intimate contact between the contact surface. So when there is lack of intimate contact between the contact surfaces that actually enhances the contact resistance. So once there is a contact resistance is very high and the requirement of the welding current is less in this cases and sometimes it promotes the electrode sticking to the workplace.

So if you use the maximum nugget diameter is about 33% of the electrode diameter, chances of the electrode sticking is more in microwelding mode since electors are not wire cooled. So what are the heat is generated between the electrode in the workplace specifically in microwelding process, so electrode size is very small, so there is no scope to use some kind of the cooling system there.

So in that cases the heat transfer may not be effective as like as the conventional process. So there is sometimes in microwelding processes, there is chances for the development of the heat generation at the contact surface and this mostly used for the non-ferrous metals and alloys such as copper, nickel, platinum, aluminium, all this kind of materials we normally use for the resistant microwelding process.

But for regular welding process mostly or conventional welding process, conventional resistance spot welding process mostly steel we normally use or seats for microwelding often quoted with the gold, silver, nickel, tin so that having some influence of the heat transfer mechanism of service quality also, but for regular we use normal for regular means for conventional resistance spot welding process we normally use the unquoted or unquoted seat with the zinc that is the more applicable in the automobile industry.

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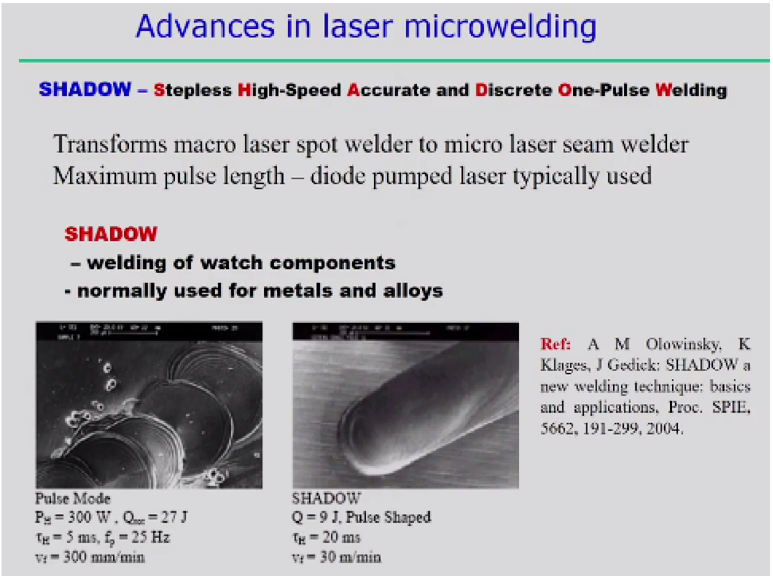

Now there are so many advancements in the laser microwelding process. One such advancement that is called the shadow technique which is stepless, high speed, accurate and discrete one pulse welding process. So in this cases transformers the macro laser spot welder to a micro SEM welder and that is the main, this conversation or such that the development of the microcell can be happen.

So maximum pulse length normally happens in case of the diode laser. So diode pump laser is mostly used for the development of the shadow technique, but in this technique if we look into that and the figure 1 and figure 2 in this cases pulse mode if you see that there is the pulse mode on and off of the laser pulse energy in this case. So here on off mode there is depends on the what is overlapping of the pulse and the shape is something like that, which is obvious from this figure also.

Now if you know what is the pulse duration of a particular laser and within that duration if we cover the particular domain then this one single pulse all energy will be deposited over this length. So that is why this is possible if you move this supplied energy for the laser as a very high speed. So within that high speed when try to move from one point to another within that high speed.

So that it will cover with in single pulse there is a coverage of the application of the pulse energy to the substance material and that clears kind of the single smooth surface as compared to the multiple overlapping surface what we normally observe in case of the spot welding process. So that is the difference and this is called the shadow technique and this normally used for the welding of the watch component that means shadow is mostly applicable in case of the metallic material.

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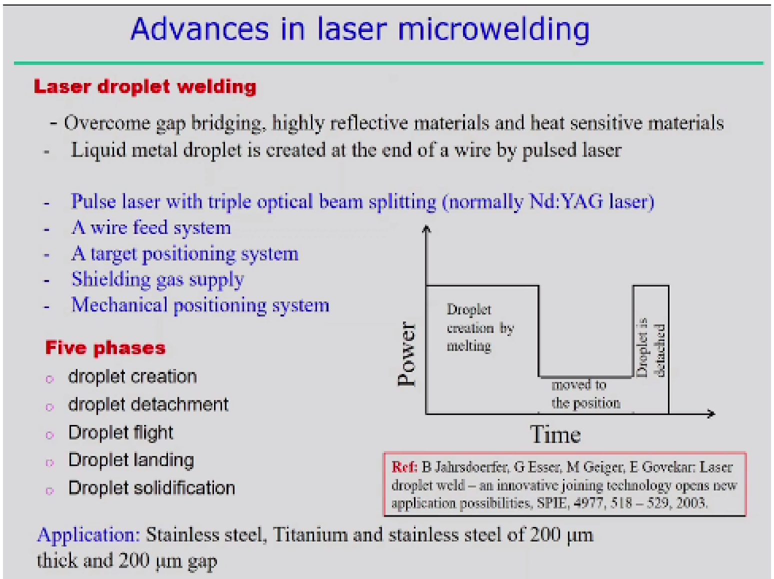

Other advance in the laser microwelding for example, laser droplet welding in this case is the overcome the gap bridging and highly reflective materials and high heat sensitive materials. So in this cases when there is a gap between these 2 components so to get successful joint between these 2 components having little bit more gap and of course in that microscale then liquid metal droplet is created by using the end of the wire by the pulse laser.

By application of the pulse laser at the end of the wire droplet is created and droplet is filled at the interface. So in this case the steps are like something like that. Special pulse laser with a triple optical beam splitting actually the laser dividing into 3 splitting beams and normally Nd:YAG laser is used and we use the wire feed system such that target positioning system, so we need to correctly position the drop at exactly the interface between these 2 component supposed to join.

Shielding gas assembly that is the part of the system and of course mechanical positioning system that is also to fit exactly that particular position of work piece. So it starts with this thing first droplet creation then droplet detachment from the wire, droplet flight certain distance and droplet land it and then after landing the exact position and then solidification happens, then we can get the 2 joint.

So power requirement in this case if you see the initially the droplet creation by melting then move to this position, minimum power requirement and droplet is detached then power requirement is little bit more, so with respect to time these are the requirement of the power in the particular laser droplet welding if we get the application of these things, the stainless steel, titanium and titanium and stain less steel we want to joint of 2 micrometre thickness.

But at the same time the gap between these 2 thickness is 2 micrometre gap. So that, if there is a 2 micrometre gap it is huge, if we look into the scale of this welding process. So therefore, the microscale when the gap is much more. So that gap can be filled by this liquid droplet and this technology or methodologies called the laser droplet welding process.

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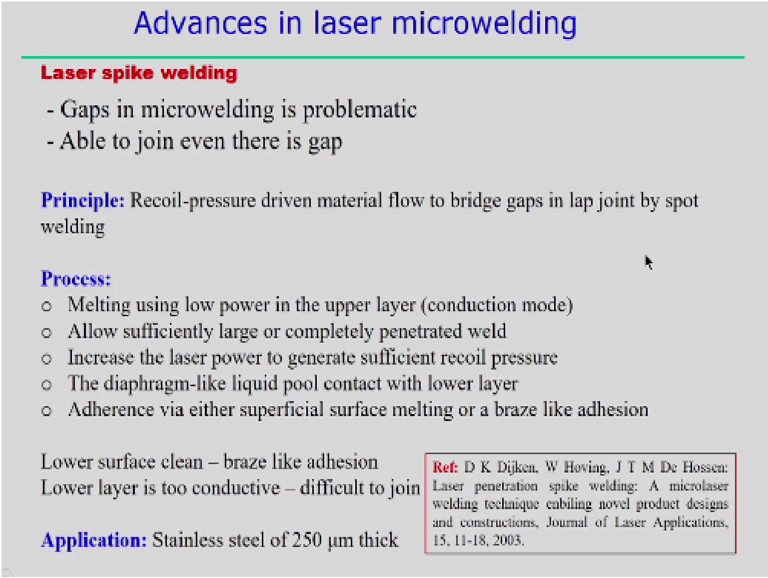

Even other development also happened that is called the laser spike welding. So in this cases gaps in microwelding is a problematic definitely here also possible to joining the gap between these 2 components. So in this case the joining, but in this case the normally we can do these thing in the lap joint configuration, lap joint configuration by spot welding, that is the principle of the joining of these 2 component.

So in the recoil pressure driven material flow to bridge the gap in the lap joint by spot welding process. Process is the melting using the low power in the upper layer. So 2 layer in the conduction mode try to keep the laser in the conduction mode, then sufficiently large or completely penetrated weld, completely penetrated weld had to reproduce, then in case the laser power to generate sufficient recoil pressure such that diaphragm-like liquid pool contact with the lower layer, such that it contact with the lower layer.

So therefore, adherence by the superficial surface welding or bridging like addition actually happens in this processes. So in this cases lower surface clean the surface clean is not good then braze like adhesion happen between these 2 component which are in the lab joint. Lab joint configuration, but there is a gap between these 2 joint. So a lower layer is the 2 conductive then it is sometimes very difficult to join between these 2 components.

Application we can get the stainless steel of 2 micrometre thickness having the sufficient gap between the 2 set in the lap joint configuration. Of course if you look into the other part this laser droplet welding actually laser droplet welding is mainly applicable for the butt joint configuration, but if you look into this laser spike welding, this is more applicable for the lap joint configuration.

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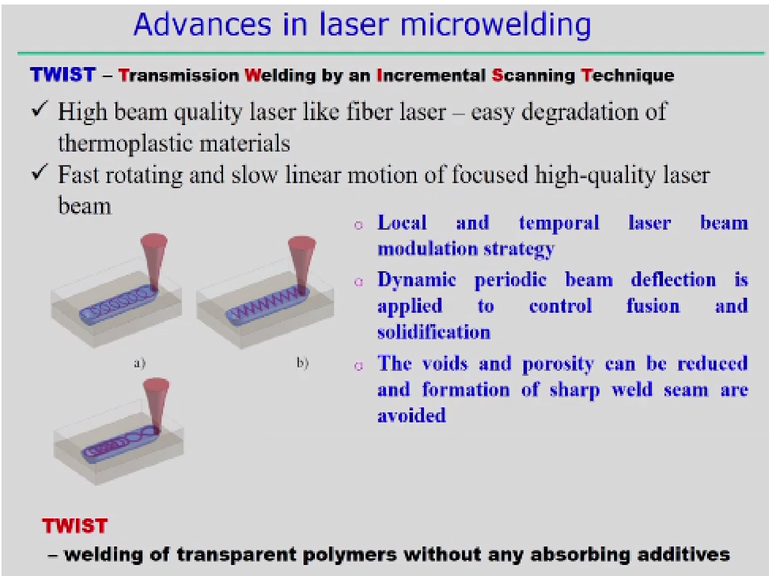

So even in case of non metallic materials there is advancement in the laser microwelding happens that is called the twist technology that transmission welding by an incremental scanning technique. So in this case high beam quality laser like fibre laser intensity is very high and easy degradation of the thermoplastic material and if you use this thing in this cases that not exactly move the path straightway of the laser rather fast rotating.

And the slow linear motion the forecast high beam laser can also be followed such that different path can be generated what has been shown in this figure. So what are the benefits we can get rather the some zigzag way to move the laser and what to design certain path and one advantage is we can get that local and the temporal laser beam modulation studies you need to know these things.

Dynamic periodic beam deflection is also applied to control the fusion and the solidification mainly that is the purpose and of course the voids and the porosity can be reduced or formation of distortion can also be reduced if we follow some kind of the zigzag path rather than the joining these 2 components following some single linear path. So welding of the transparent polymers without any absorbing additives is possible to join by using the twist technique.

Now apart from this development in the microwelding processes some development happens in the even nano bonding processor.

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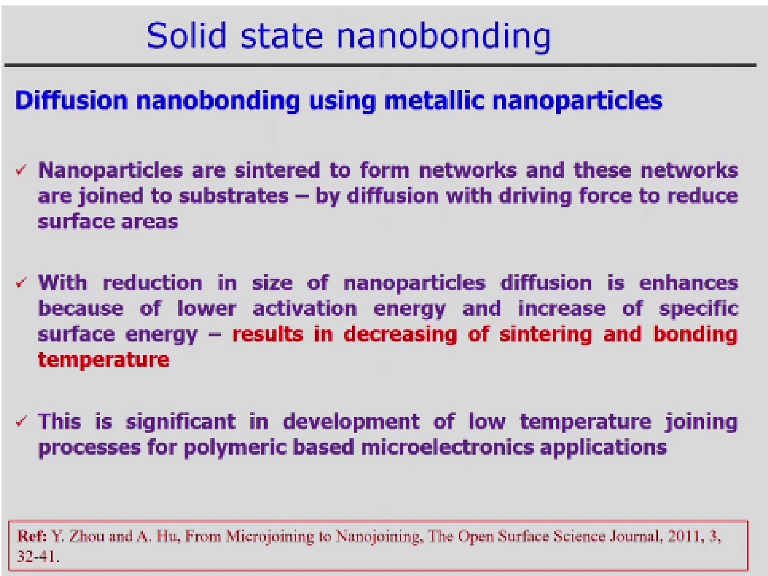

In this case one is that diffusion nano bonding using the metallic nanoparticles. In this case nanoparticles are sintered normally we already discussed the bonding with the nanoparticles. In this case nanoparticles sintered to form the networks, of this networks are joined by the substrate and it actually happens by the diffusion with the driving force to reduce the surface area.

So that is the driving force of this nanoparticles to join the components, with reduction in the size of the nanoparticles diffusion is enhances actually because of the low activation energy is required and increase in the specific surface energy that results in the decreasing of the sintering and the bonding temperature, this is one of the advancement for the lowering at the lower temperature, the joining can also be achieved.

So this is the significant development at the low temperature joining processes for polymeric based microelectronics application you can find out and the diffusion or solid state nano bonding.

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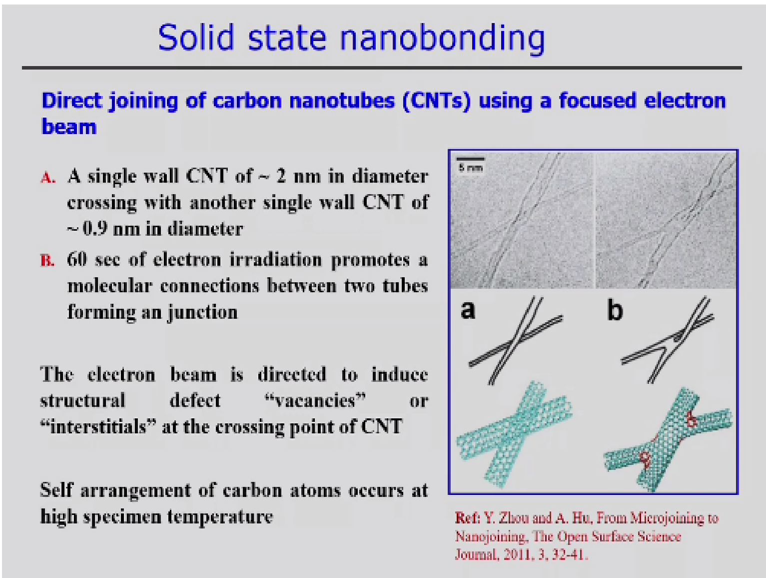

Direct joining of the carbon nanotube using the fused forecast electron beam is also possible and it also happens in the journey of the carbon nanotube. So for example, if you look into this figure the single-walled carbon nanotube of 2 nanometre in diameter crossing with another single nanometre tube CNT tube of 0.9 millimetre in diameter. So 60 second of irradiation promotes intermolecular connection between the 2 tubes forming an junction.

So then electron beam is directed to induce the structural defect because given the single wall, the diameter of this carbon nanotube using the 2 nanometre. So which is almost the size of the atoms in this case. So at the interface creation of the defects is responsible vacancies or interstitial space such that this joints can be that it can join between these 2 component. So self arrangement of the carbon atoms actually occurs at this high specimen temperature.

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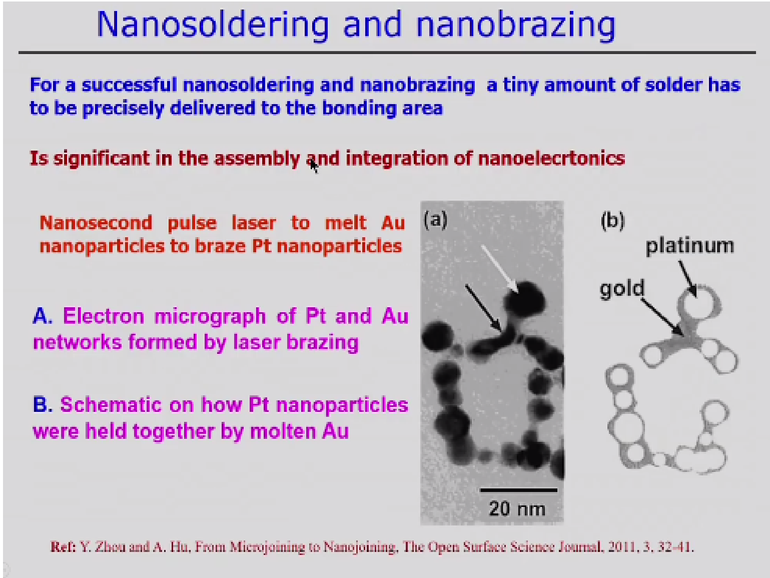

Even nanosoldering and nanobrazing has been developed if you see in there for successful nanosoldering or nanobrazing, tiny amount of the solder has to be precisely delivered to the bonding area. So if you see this figure that assembly and the integration of the nanoelectronics in this cases. So nanosecond pulse laser is used to melt the gold nanoparticles to braze the platinum nanoparticles.

So here gold nanoparticles to braze with the platinum nanoparticles and very precisely we need to apply the gold nanoparticles. So electron micrograph of the platinum and gold network that actually formed by laser brazing if you see here and schemating on how platinum nanoparticles held together by the gold, here it is given here. So it is possible to development of the joining of this components in the event at the nanoscale and that may be applicable in particular nano devices.

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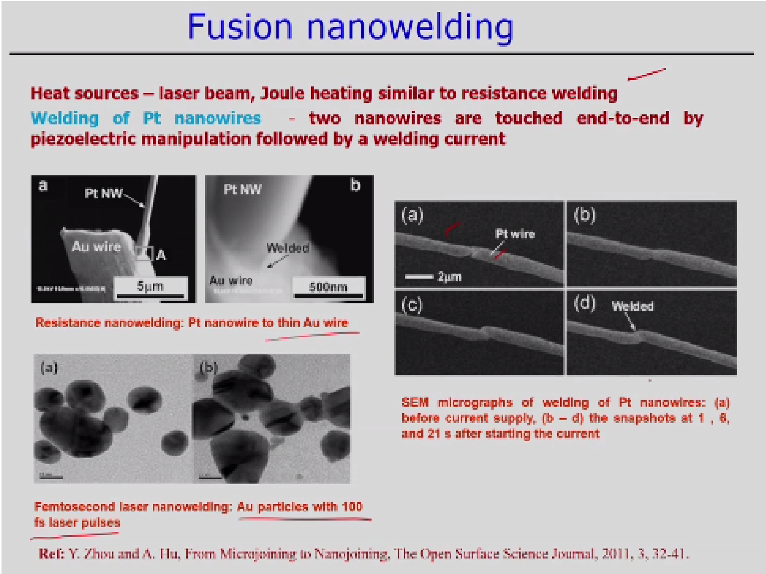

Even fusion nanowelding also developed in this case, in case of fusion nanowelding, the heat source can be used like the laser beam, Joule heating similar to the resistance welding can also be applicable in this cases. Example is the welding of the platinum nanowires. So 2 nanowires are touched end to end if you see the 2 nanowires end to end touch and by piezoelectric manipulation.

Because only it is possible to bring these 2 nanotubes platinum wire, nanowire to bring together such that the interface and piezoelectric manipulatory is actually required and after that apply the current and then it creates some resistance process and the resistant nanowelding we can see here platinum nanowire to thin gold where the resistance nanowelding has been developed also.

And but in this case if you see the femtosecond laser with the application of the femtosecond laser nanoparticles with 100 femtosecond laser pulses is possible to join together in this case. apart from that here is the welding of the platinum and nanowire before current supply even here the application before current supply and b to d and the snap shots after 21 seconds starting of this thing. So that after application of this, the development of this, joining of these 2 tube happens in this nanowelding process.